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Consistency of parameters derived from global SLR, VLBI and GNSS solutions when using non-tidal loading deformation on the observation level

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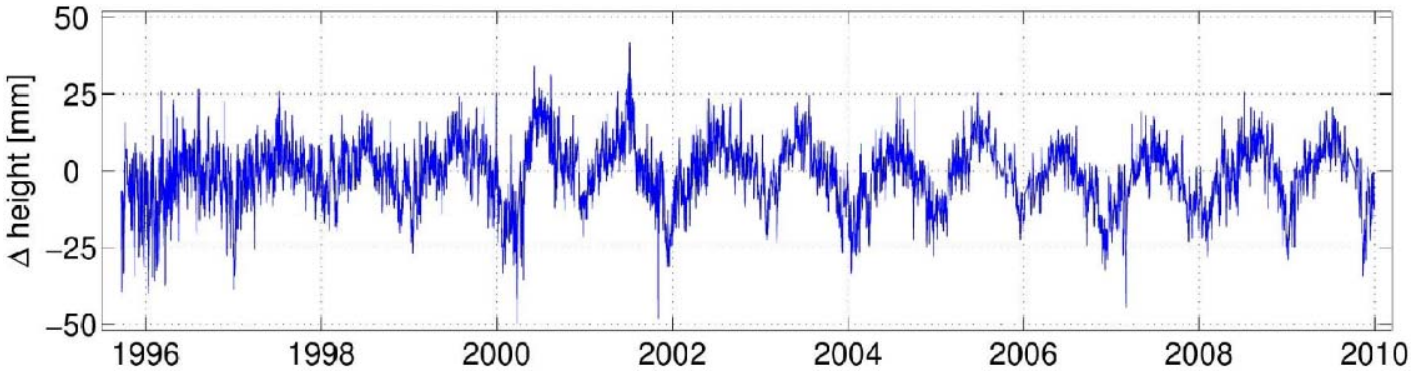
Motivation



- Redistributions of masses in the atmosphere, oceans and the continental water storage lead to station displacements, changes in Earth rotation and in the Earth‘s gravity field
- Unmodelled non-tidal displacements are a limiting factor of recent ITRF realizations

⇒ Include non-tidal loading for SLR, VLBI and GNSS analysis (observation level)

- What happens to technique specific parameters?
- Is the consistency of common parameters improved?

Solutions generated

	VLBI	SLR	GNSS
Data processed	R1 / R4 sessions	LAGEOS 1/2 Etalon 1/2	GPS / GLONASS (CODE ITRF2013 reprocessing)
Timespan	2001 - 2010	2001 - 2011	2001 - 2012
Software	Calc/Solve Software	Bernese GNSS Software	Bernese GNSS Software
Stations	32	51	345
Deformation	Timeseries (bilinear interpolated)	Gridded (bilinear interpolated)	Gridded (bilinear interpolated)
Models	Def: NASA GSFC	Def: NASA GSFC / Luxembourg Grav: GFZ AOD R5	Def: NASA GSFC Grav: GFZ AOD R5

Five solution types:

No models

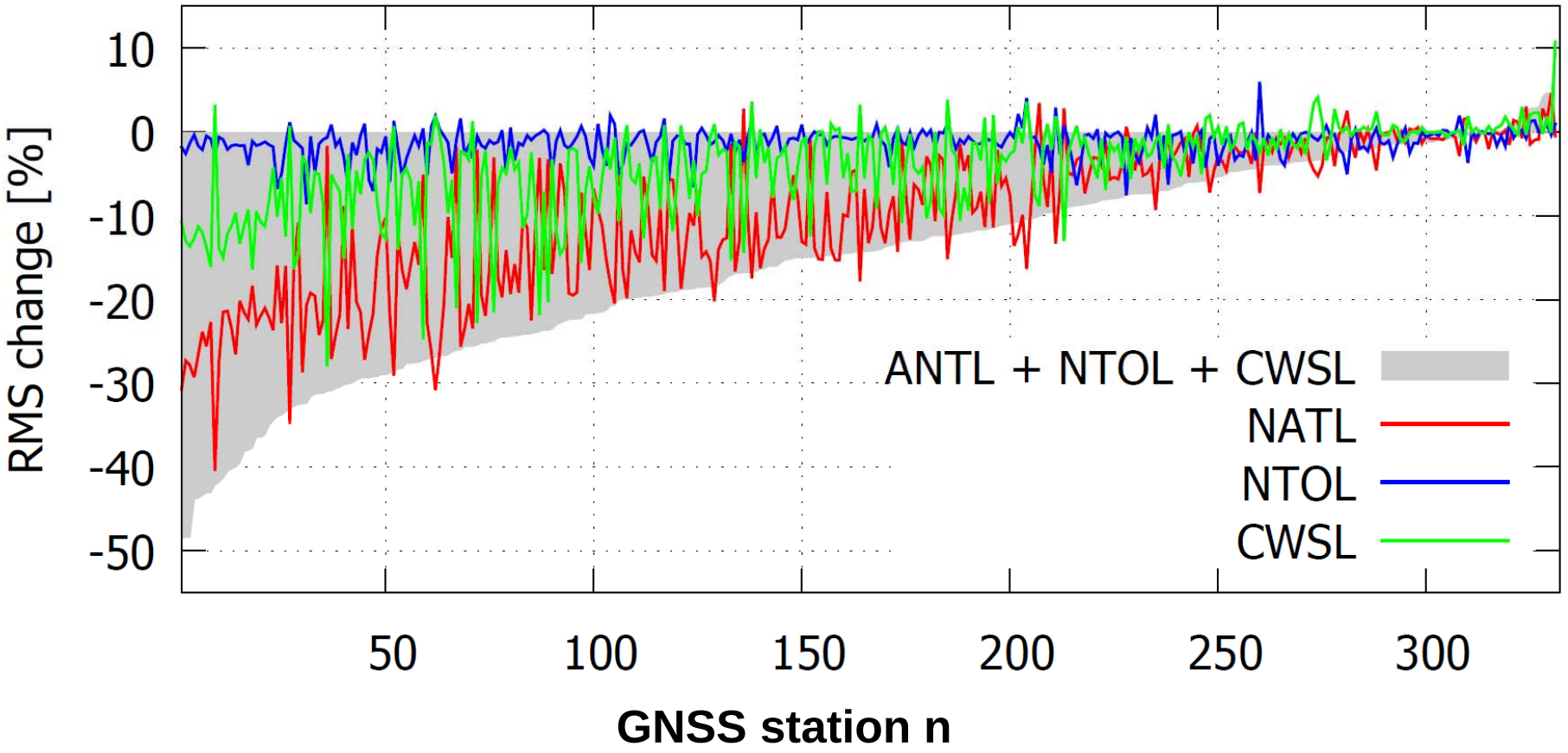
Only NATL

Only NTOL

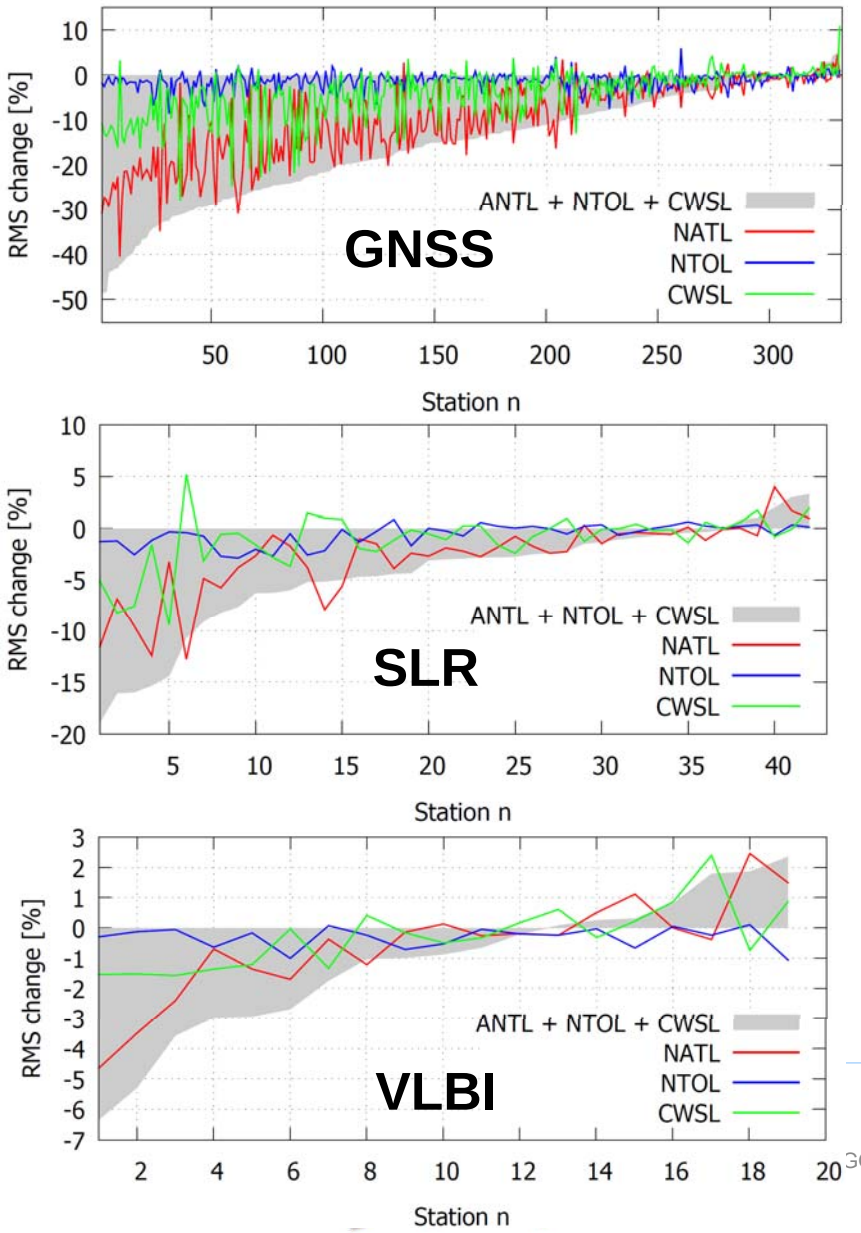
Only CWSL

All models: NATL + NTOL + CWSL

Station height: RMS change wrt. ref. solution



Station height: RMS change wrt. ref. solution



	max. increase [%]	max. decrease [%]	Median [%]
GNSS	11.1	-49.0	-8.8
SLR	3.3	-19.0	-2.9
VLBI	2.3	-7.4	-0.9

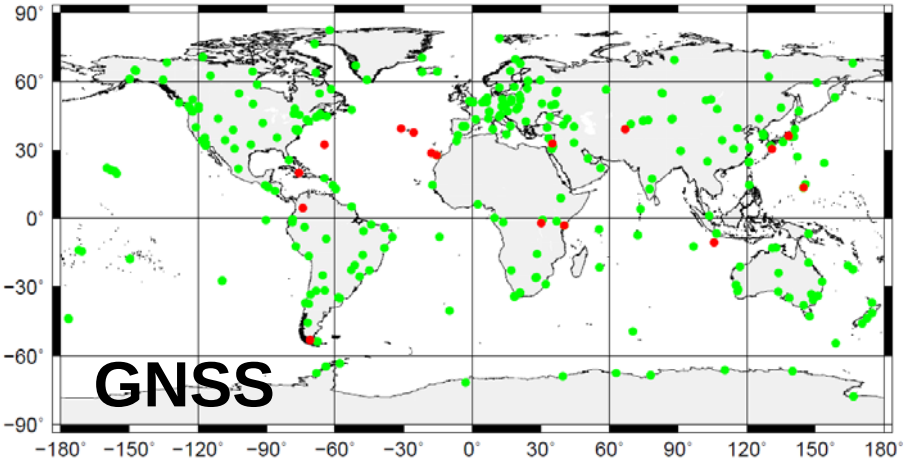
% of stations with improvement:

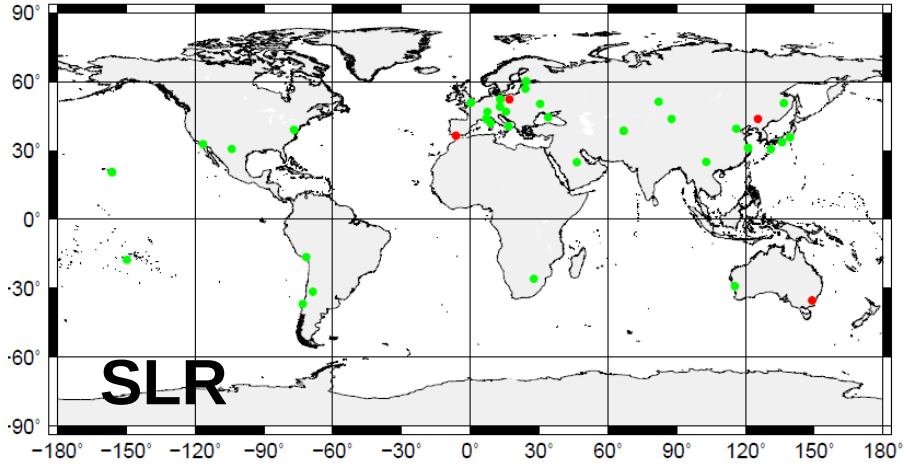
	NORTH	EAST	UP
GNSS	93.1	68.4	93.1
SLR	83.7	79.1	88.4
VLBI	80.0	75.0	65.0

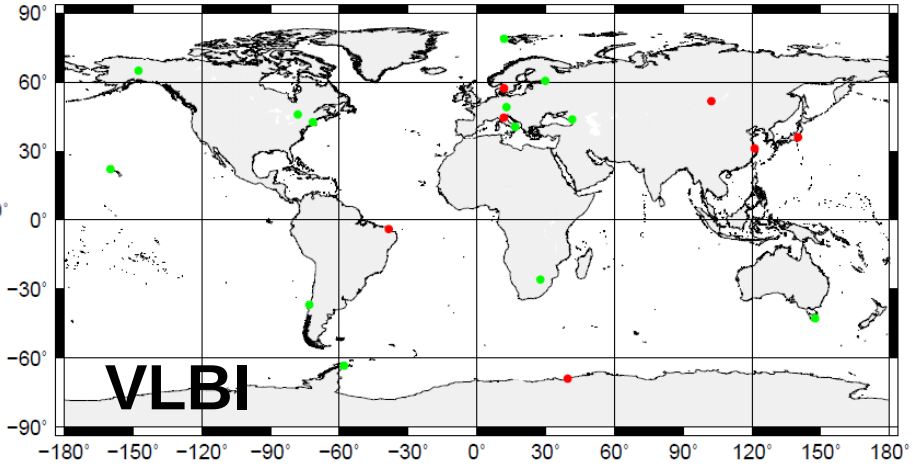
Station height: RMS change wrt. ref. solution

Green = improvement with models **red** = degradation

NATL + NTOL + CWSL







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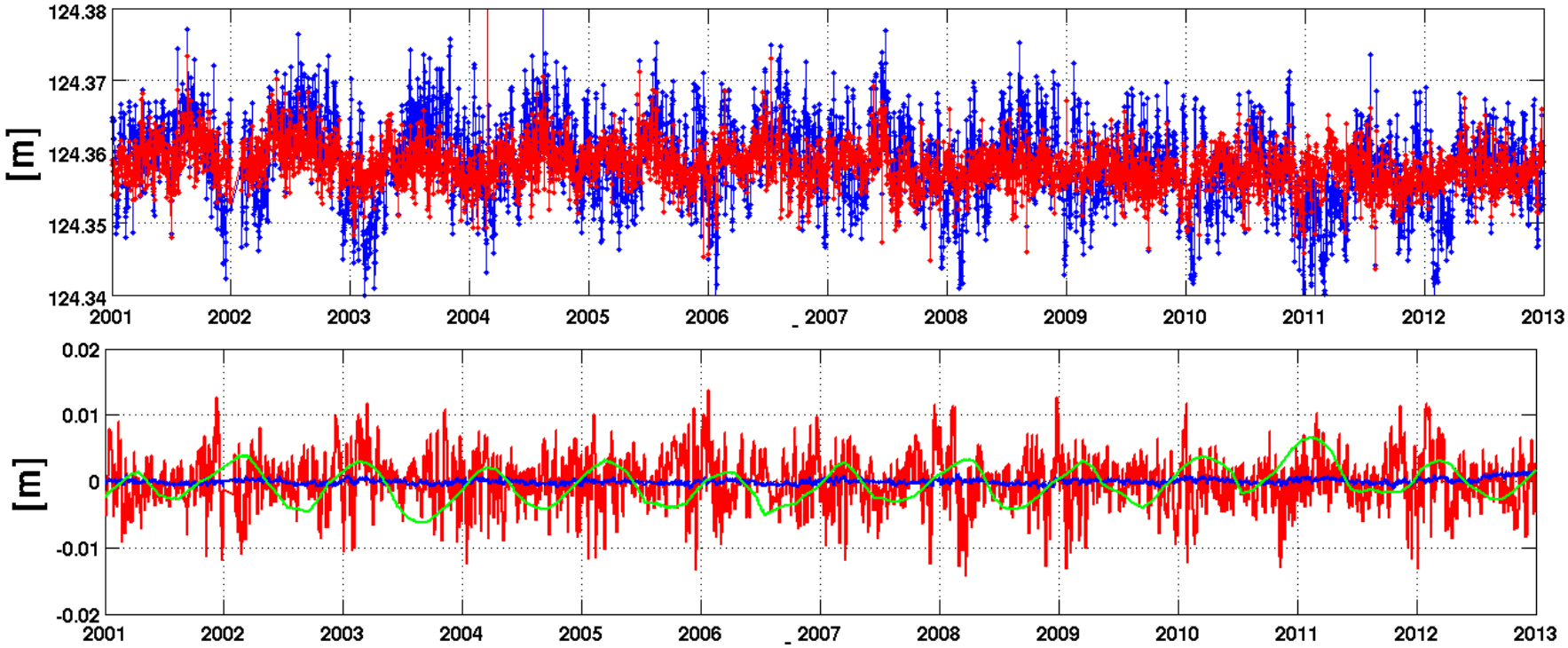
GNSS station coordinates (UP): BOR1



Improvement of RMS from

5.6 to 2.9 mm

	CWSL [mm]	NTOL [mm]	NATL [mm]
RMS	2.8	0.4	3.8

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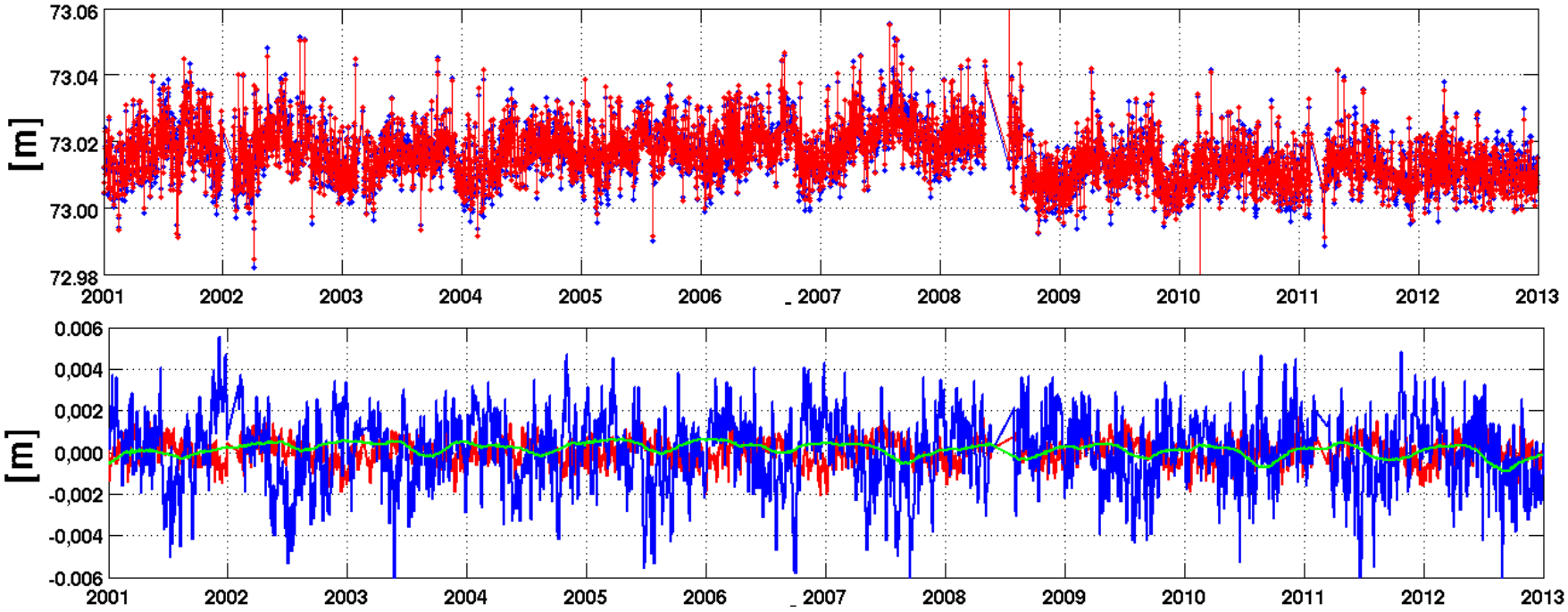
GNSS station coordinates (UP): KERG



Only improvement of RMS from

7.2 to 6.6 mm

	CWSL [mm]	NTOL [mm]	NATL [mm]
RMS	0.4	1.7	0.6

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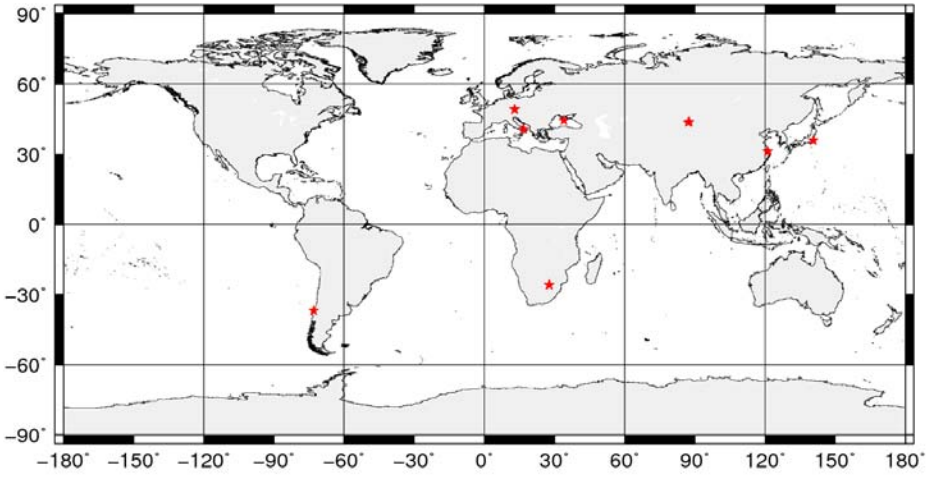
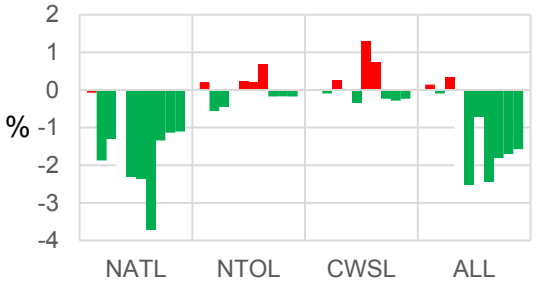
Co-locations: Stability of coordinate difference vectors

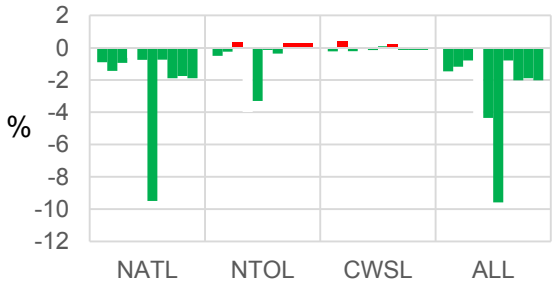
- Calculation of difference vector between reference points at stations where all three techniques are installed
- ***87% of co-location vectors are improved when all three loading models are used***



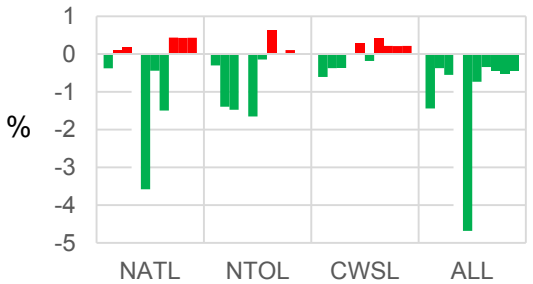
GNSS – SLR (change std.dev. UP)



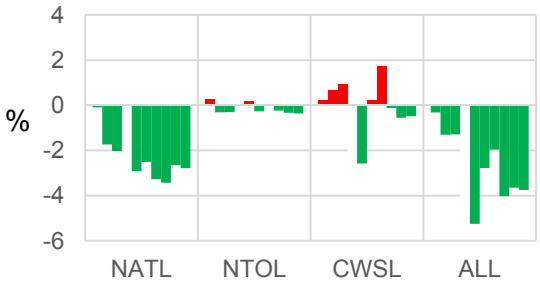
GNSS – SLR (change std.dev. EAST)



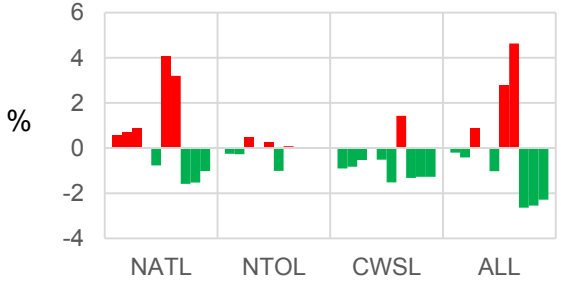
GNSS – SLR (change std.dev. NORTH)



GNSS – VLBI (change std.dev. UP)



GNSS – VLBI (change std.dev. EAST)



GNSS – VLBI (change std.dev. NORTH)

Earth Orientation Parameters: Consistency between techniques

- Comparisons done at 12 UT / VLBI mid-epochs
- ***Consistency is improved in most cases***
- Reason for worse VLBI-GNSS comparison is not yet clear

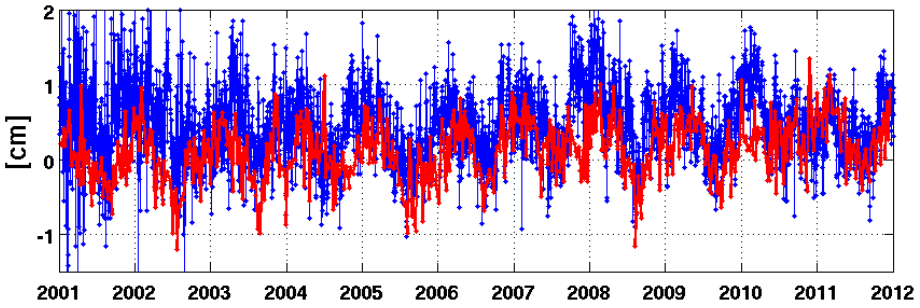
	WRMS SLR-GNSS			WRMS VLBI-SLR			WRMS VLBI-GNSS		
	X Pole	*Y Pole*	*LOD*	*X Pole*	*Y Pole*	*LOD*	*X Pole*	*Y Pole*	*LOD*
	µas		*µs/d*	*µas*		*µs/d*	*µas*		*µs/d*
Non	174.2	171.0	50.1	350.4	386.2	45.5	301.0	327.5	23.8
NATL	172.3	168.7	50.1	349.4	387.2	45.5	300.6	329.2	23.8
NTOL	174.4	170.9	50.2	350.2	385.8	45.5	301.0	326.8	23.8
CWSL	173.8	170.2	50.1	352.1	389.0	45.5	302.8	329.8	23.8
NATL+ NTOL+ CWSL	171.6	167.8	50.0	349.9	389.7	45.4	302.8	330.9	23.8

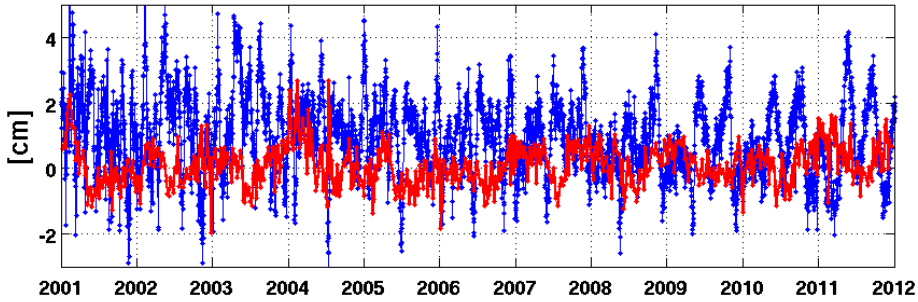
Geocenter

- Geocenter is a common parameter in SLR and GNSS processing
- **SLR series** → signal reduction in all components
- **GNSS series** → signal reduction only in X/Y components

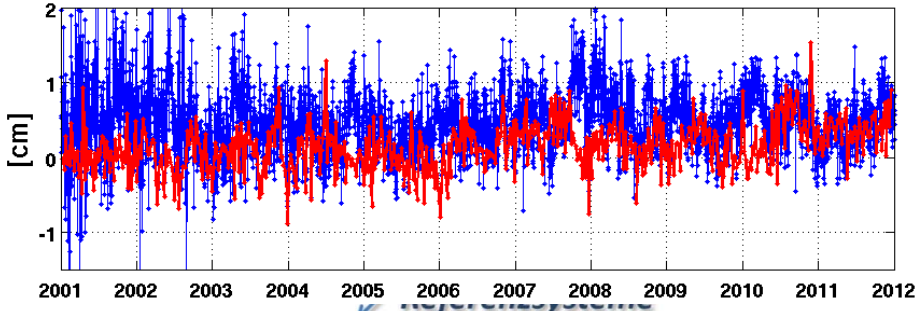
GCC-X **GCC-Z**

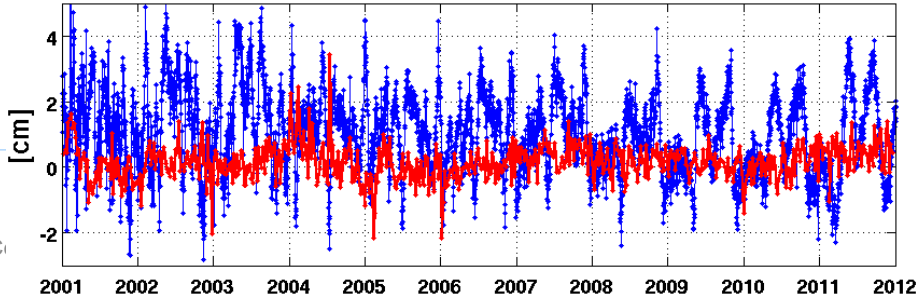
NO loading models applied





All models applied: NATL + NTOL + CWSL





Summary

Non tidal displacement models for NATL, NTOL and CWSL used at the observation level in global GNSS, SLR and VLBI analysis

- Station coordinates
  - Timeseries RMS can be reduced by using loading models
  - Co-location vectors between techniques are more stable
- EOP
  - Differences between techniques could be reduced in most cases
- Geocenter
  - Yearly signal in SLR series can fully be explained by the sum of NATL, NTOL and CWSL
  - WRMS of the individual time series was reduced in all cases, except for Z component from GNSS (orbit modelling issues at draconitic period)

Thank you for your attention!

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This work was funded by the DFG as a part of the Research Project (FOR1503): **„Space-Time Reference Systems for Monitoring Global Change and for Precise Navigation in Space“**

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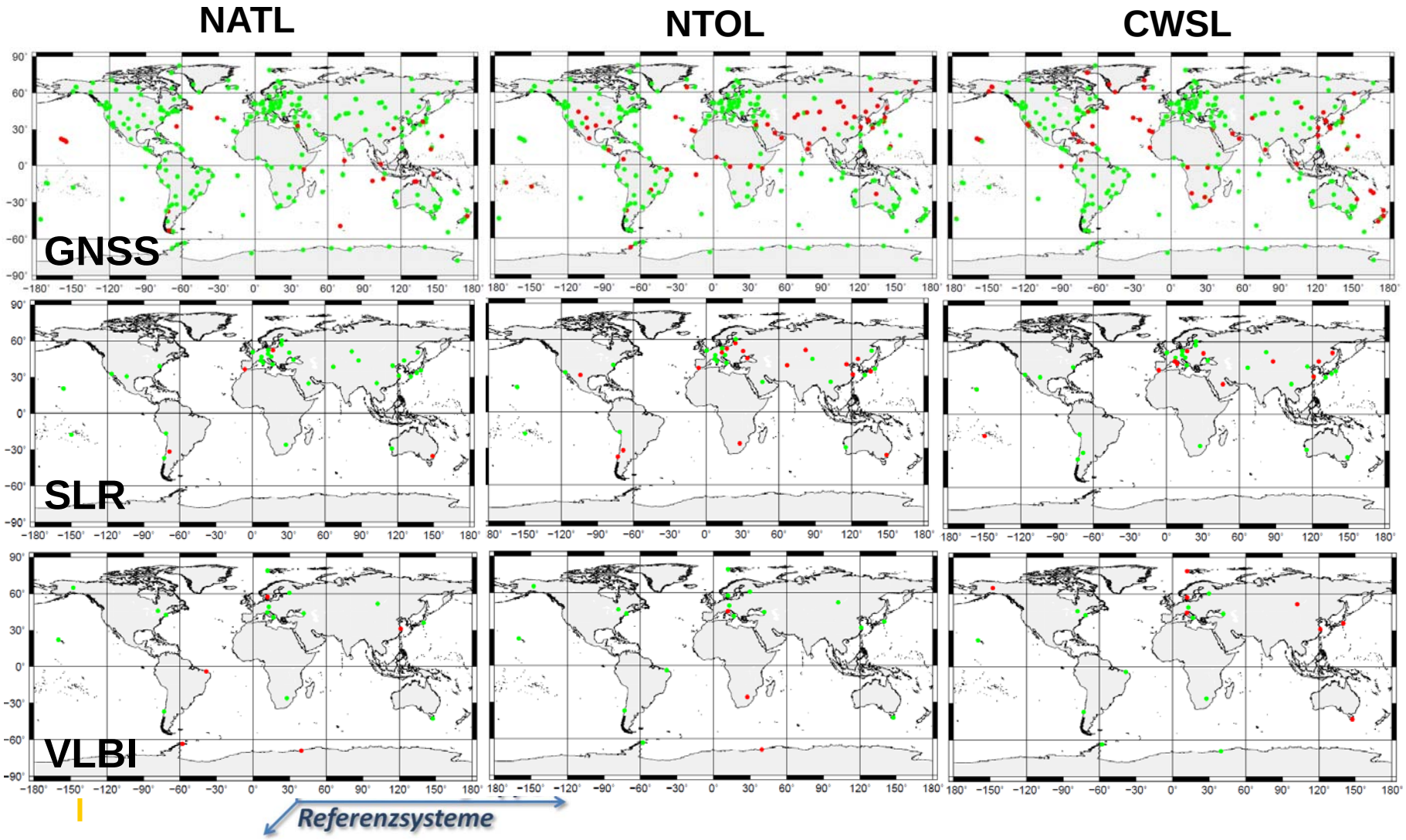
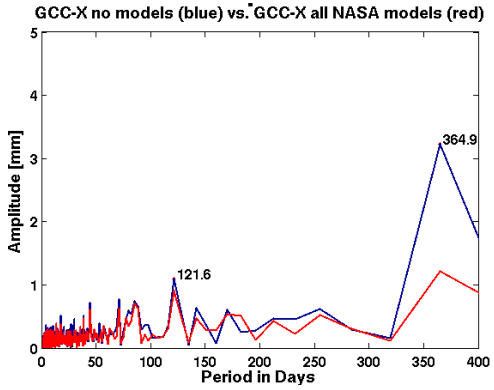
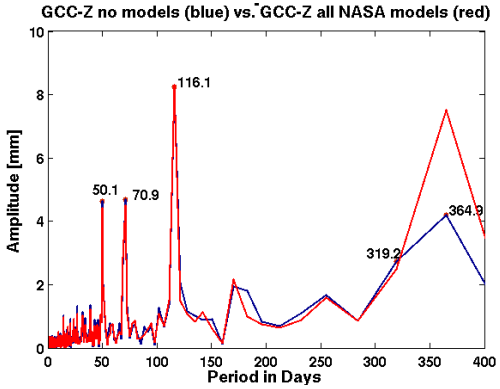
Station height: RMS change wrt. ref. solution

Green = improvement with models **red** = degradation



Geocenter – frequency domain





GNSS

X / Y components:

- 50% reduction of yearly amplitude

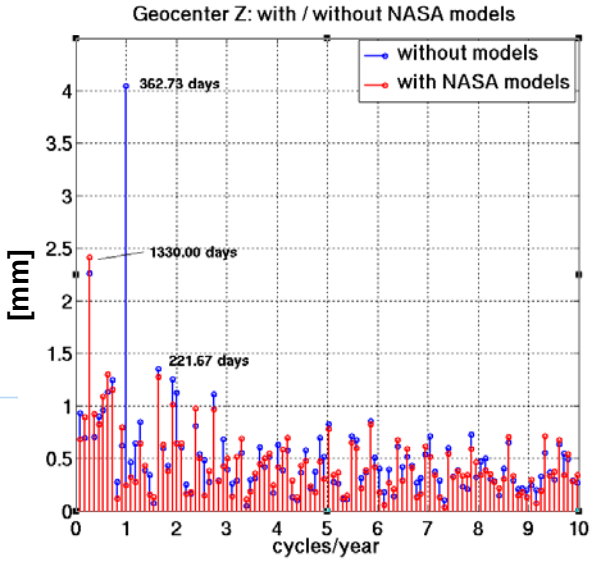
Z component:

- 90% increase of yearly amplitude
- Orbit modeling issues visible (draconitic year)
- Short timeseries → separation impossible

SLR

X / Y / Z components:

- Yearly variations can be fully explained by the sum of NATL, NTOL and CWSL



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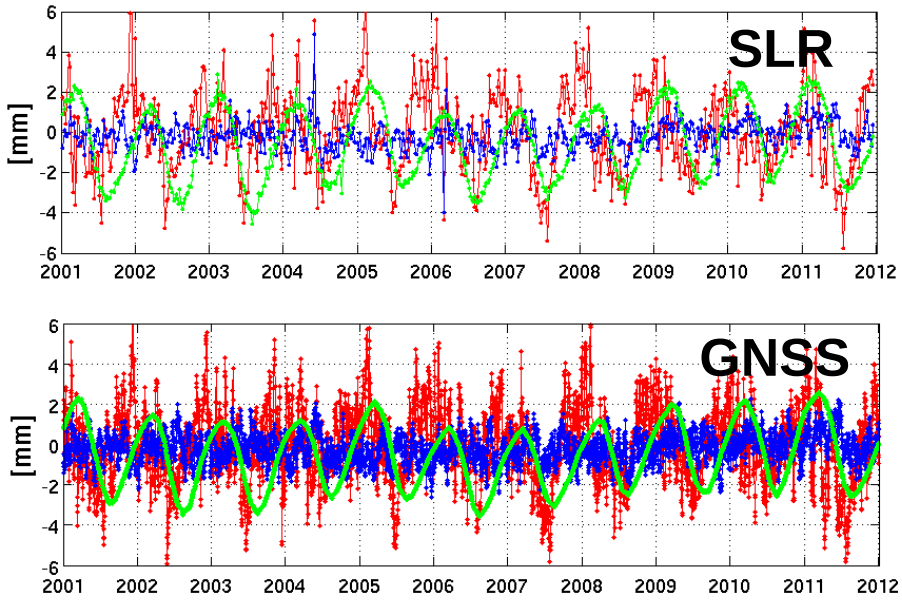
Geocenter – model impact

- Model impact nearly identical
- SLR → WRMS is reduced for all components
- GNSS → WRMS is reduced for X / Y
  → WRMS increase for Z

Correlation (GNSS and SLR impacts)

	X	Y	Z
NATL	0.81	0.87	0.88
NTOL	0.87	0.58	0.81
CWSL	0.98	0.95	0.98

Model impact UP component



Weighted RMS of GCC series

		WRMS [mm]		
		X	Y	Z
GNSS	No model	6.83	6.23	14.87
	NATL	6.67	5.88	14.98
	NTOL	6.57	6.21	14.95
	CWSL	6.72	6.23	15.44
	NATL+NTOL+ CWSL	6.40	5.88	15.68
SLR	No model	4.11	3.32	5.88
	NATL	3.88	2.99	5.33
	NTOL	3.77	3.28	5.75
	CWSL	3.63	3.12	5.31
	NATL+NTOL+ CWSL	3.27	2.71	4.89

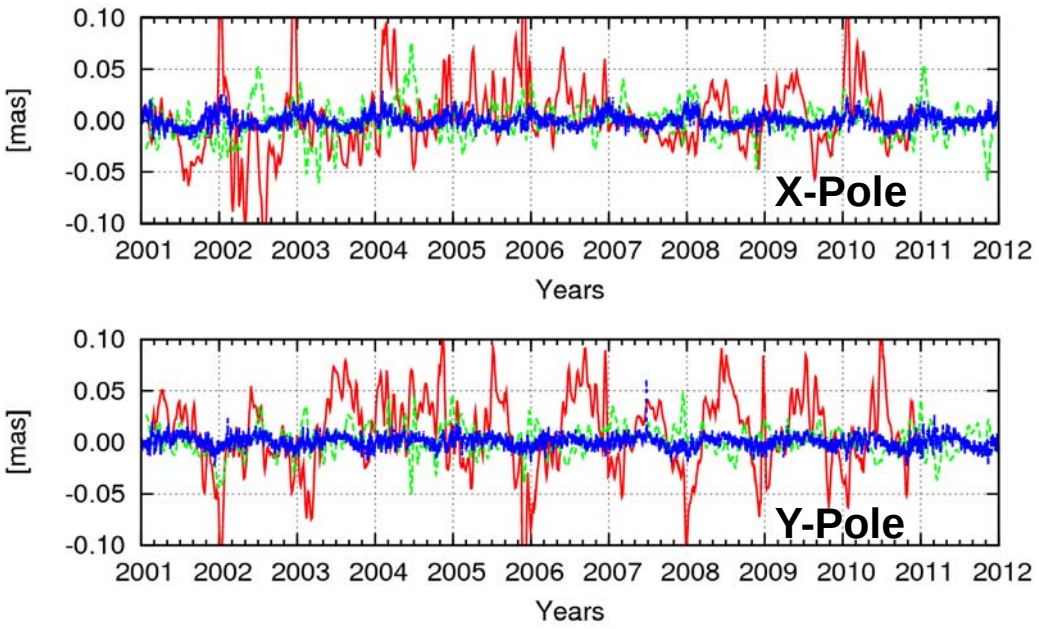
EOP – impact of loading models

WRMS	GNSS			SLR			VLBI			
	X Pole	*Y Pole*	*LOD*	*X Pole*	*Y Pole*	*LOD*	*X Pole*	*Y Pole*	*UT1UTC*	*LOD*
	µas		*µs/d*	*µas*		*µs/d*	*µas*		*µs*	*µs/d*
NATL	5.0	5.6	0.2	24.1	22.5	3.1	50.8	43.8	2.0	0.5
NTOL	1.9	1.3	0.1	21.9	15.5	2.8	40.5	35.3	1.5	0.5
CWSL	1.9	3.1	0.0	6.9	6.6	0.1	8.5	8.8	0.4	0.1
NATL+NTOL +CWSL	6.1	5.9	0.2	27.8	24.9	2.4	24.5	20.6	1.1	0.0

- Biggest WRMS for VLBI Pole coordinates
- Biggest impact from NATL and NTOL
- Network distribution may be the reason for stronger impact in VLBI and GNSS

Impact of the sum of NATL, NTOL, CWLS

(red: VLBI, green: SLR, blue: GNSS)



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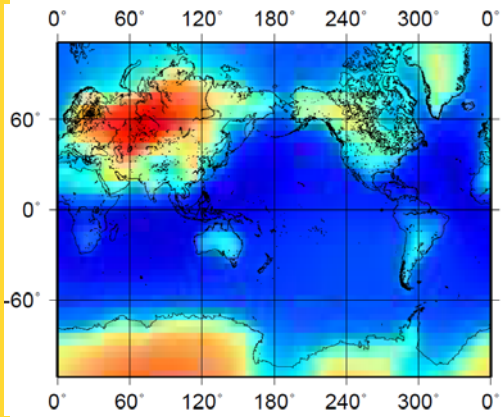
Models used

- Geometry (non-tidal) :
  - atmosphere (NATL)
  - ocean (NTOL)
  - continental water storage (CWSL)

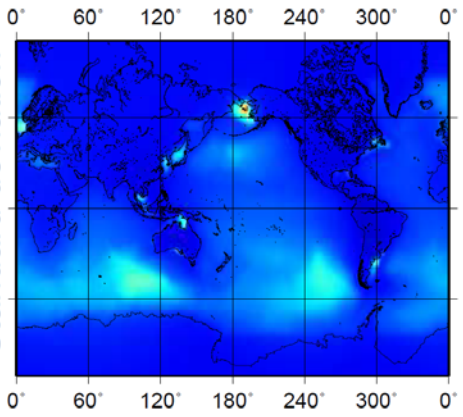
→ ***NASA GSFC VLBI group***

- Gravity (static) : EGM2008
  (variable) : GRACE AOD Release 5 product (GFZ)

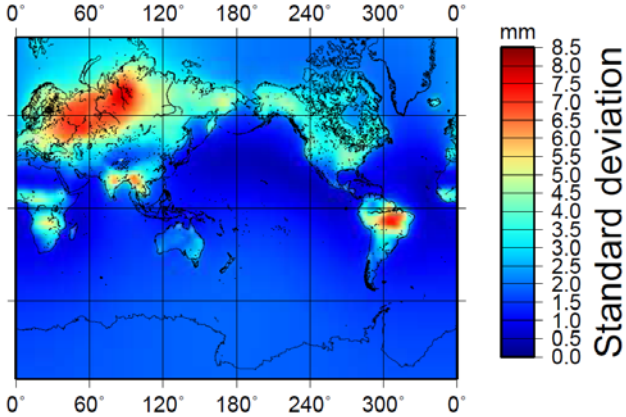
NATL



NTOL (after detrend)



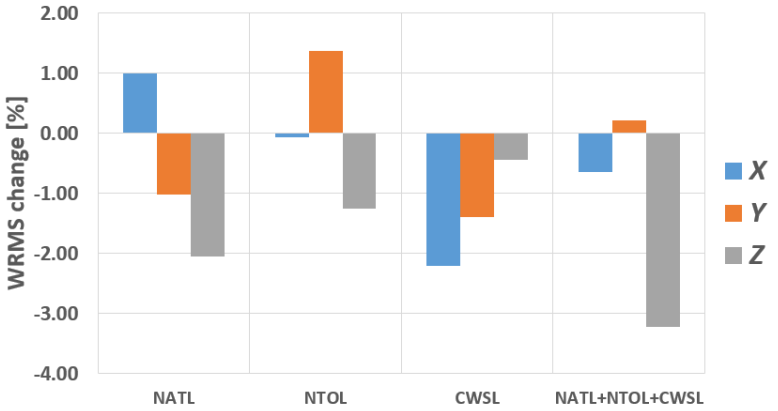
CWSL (after detrend)



Geocenter – Difference WRMS

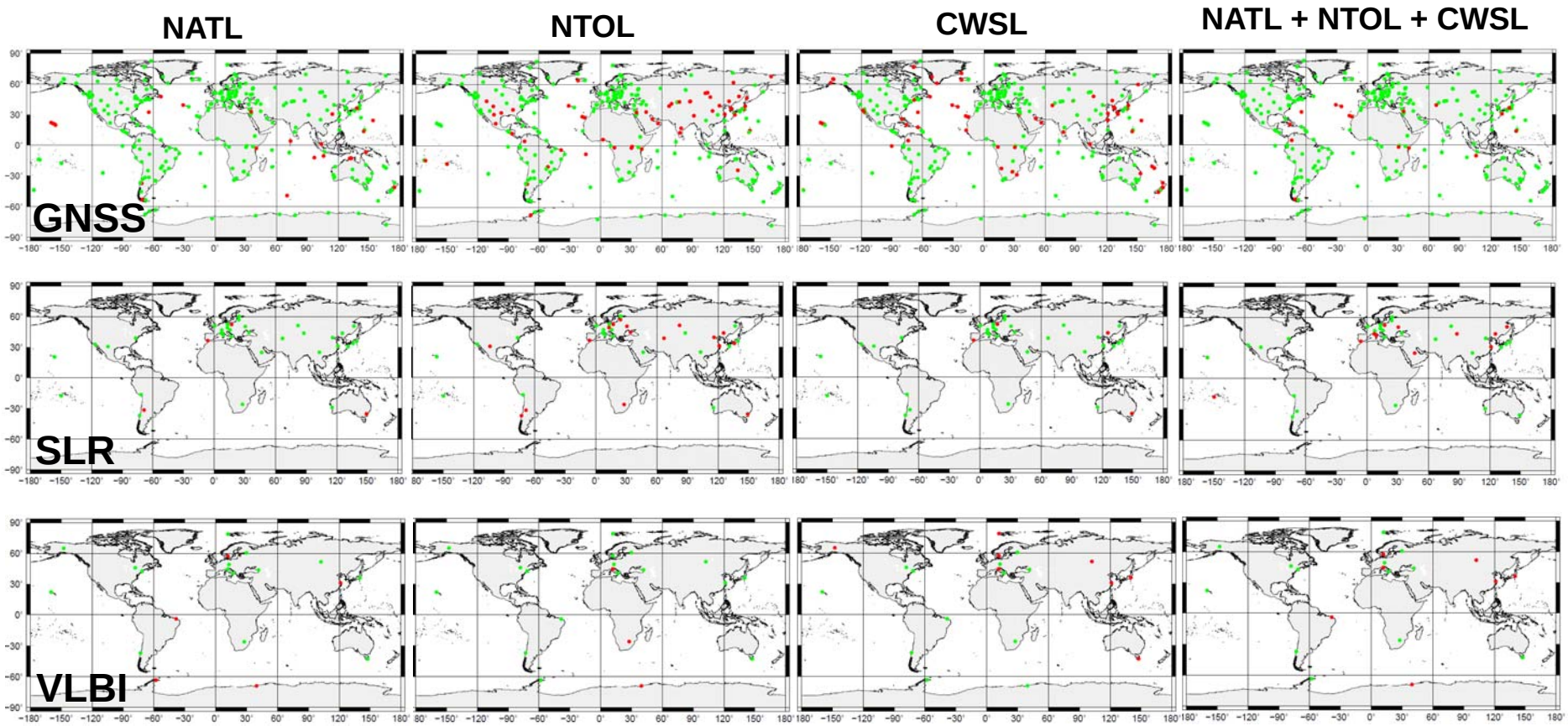
- Daily GNSS GCC estimations → weekly weighted means
- WRMS of differences to SLR estimations
- Calculation per individual model combination
- Differerences WRMS reduced in nearly all cases
- Exceptions:
  - X when only NATL is used
  - Y when only NTOL is used
  - Y when the sum of NATL, NTOL and CWSL is used

	WRMS [mm]		
	X	Y	Z
No model	5.12	4.87	16.27
NATL	5.17	4.82	15.94
NTOL	5.12	4.94	16.07
CWSL	5.01	4.80	16.20
NATL+NTOL+CWSL	5.09	4.88	15.75

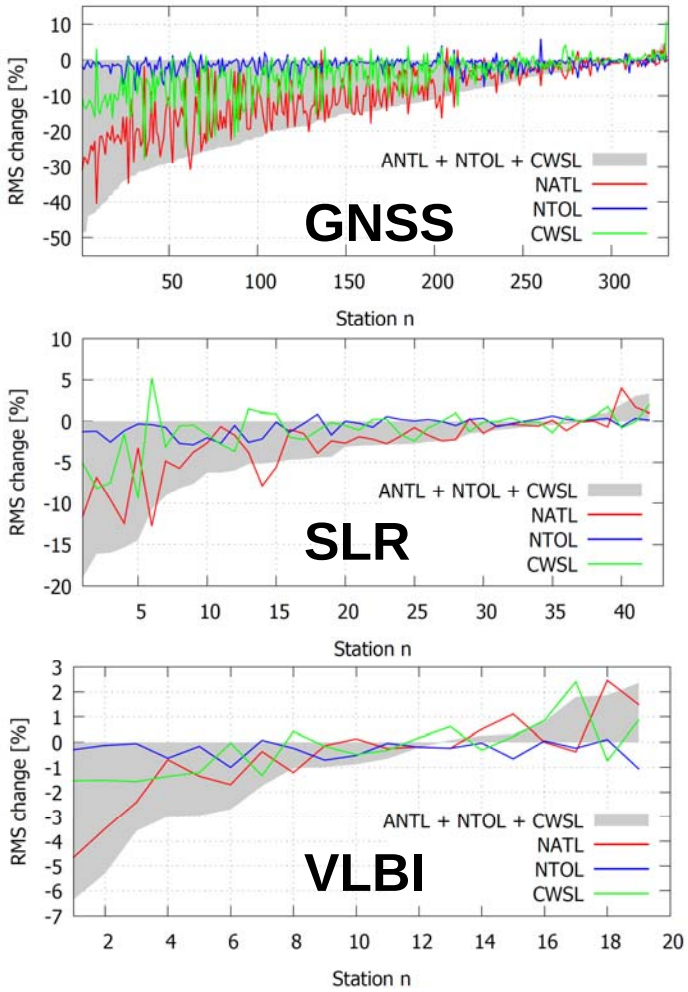


RMS change wrt. ref. solution (up)

Green = improvement with models **red** = degradation



RMS change wrt. ref. solution (up)



	max. increase [%]	max. decrease [%]	Median [%]	% of stations with improv.
North	11.1	-32.0	-8.8	93.1
East	690.9	-93.1	-23.7	68.4
Up	11.0	-51.3	-14.2	95.2

	max. increase [%]	max. decrease [%]	Median [%]	% of stations with improv.
North	1.8	-7.6	-1.9	83.7
East	2.9	-7.6	-1.3	79.1
Up	3.3	-19.0	-2.9	88.4

	max. increase [%]	max. decrease [%]	Median [%]	% of stations with improv.
North	1.9	-5.5	-0.9	80.0
East	0.5	-9.4	-0.8	75.0
Up	2.3	-7.4	-0.9	65.0